

Bicyclist head injury prevention by helmets and mandatory wearing legislation in Victoria, Australia

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After a decade of promotion and education, legislation for mandatory helmet wearing by bicyclists in Victoria was introduced on 1 July 1990. The legislation was a world first. Comparison of 1710 bicyclist casualties wearing and not wearing helmets has demonstrated that wearing helmets certified to the Australian Standard reduces the head injury risk by at least 39% and lessens head injury severity. Simulated impact testing of helmets has shown that they provide protection in most impacts including collisions involving a motor vehicle. Legislation for mandatory helmet wearing in Victoria has led to increased wearing rates and marked reductions in bicyclist fatalities and head injuries. The Victorian experience gives substantial support to the introduction of legislation for mandatory helmet wearing by bicyclists.

The markedly higher frequency of head injury in Victorian bicyclists, fewer than 5% of whom wore helmets, compared with motorcycle riders, virtually all of whom were helmeted (1), in conjunction with the marketing in 1981 of the first bicyclist safety helmet approved by the Standards Association of Australia (SAA) (2) led the Victorian Road Trauma Committee of the Royal Australasian College of Surgeons (VTRC) to

initiate the promotion of voluntary helmet wearing statewide and subsequently legislation for mandatory helmet wearing (3). In December 1981, a special meeting was convened by the VTRC with invited representatives of organisations potentially interested in the promotion of helmet wearing. Information was disseminated to private and government schools, tertiary institutions and bicyclist organisations. Bulk helmet purchase schemes to reduce costs were developed and a \$12 Government rebate sought on the purchase of approved helmets. Schools were requested to require students riding bicycles to and from school to wear helmets. Submissions were made to the Government for the development of a bicyclist traffic safety policy by the Department of Education and for a commitment to introduce legislation for compulsory helmet wearing (3). In 1984 the Road Traffic Authority established a multidisciplinary helmet promotion task force and a mass media publicity campaign was targeted at the parents of primary school children (4). Throughout the 1980s the press, radio and television gave continuing publicity to the promotion of helmet wearing.

The results of a study by the VTRC of consecutive bicyclist and motorcyclist casualties treated at four Melbourne teaching hospitals showing that unhelmeted bicyclist casualties sustained significantly more frequent and severe head injuries than unhelmeted motorcyclists, although the latter sustained greater severity of overall body injury (5,6), was used to publicise further the high vulnerability of Victorian bicyclists to head injury in accidents and to promote helmet wearing.

In December 1984 the Government acceded to our request for the introduction of a helmet rebate scheme and high volume sales followed (3).

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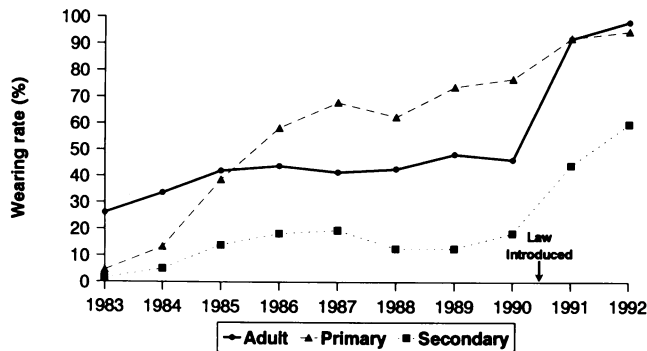


Figure 1. Age-specific helmet wearing rates among commuter bicyclists in metropolitan Melbourne: 1983–1992.

In 1987 the Social Development Committee of the Parliament of Victoria, rejecting its earlier opinion that the social costs of mandatory wearing legislation were not acceptable to the people of Victoria, recommended the introduction of the legislation (7).

A cost-benefit analysis of the foreshadowed effects of mandatory wearing legislation was undertaken in 1990 by Vic Roads (8). The costs over a 10-year period were estimated to be \$59.3 million and the benefits \$108.7 million.

The overall voluntary helmet wearing rate in Victoria increased from 5.2% in 1983 to 19.8% in 1986 and attained 30.9% in 1990 before legislation (9). Prior to legislation in 1990 the wearing rates for Melbourne primary and secondary schoolchildren riding to and from school were 76.8% and 18.4% respectively, and for adult commuter bicyclists 46.2% (Fig. 1) (9).

By 1990 the range of approved and aesthetically pleasing helmets available had widened considerably. A mass media publicity campaign and renewal of the helmet rebate scheme preceded the introduction of legislation for compulsory wearing on 1 July 1990. The law requires all bicyclists and bicycle passengers riding on the road, footpath, separate bicycle path or in a public park to wear a securely fitted approved bicycle helmet. The legislation was a world first.

Patients and methods

Injury profile of 1710 bicyclist casualties wearing and not wearing helmets

Between 1 April 1987 and 12 December 1987 and 9 September 1988 and 10 May 1989, data on accident circumstances, helmet wearing behaviour and injuries were collected on consecutive bicyclist casualties treated at Melbourne and Geelong public hospitals or dying at the accident scene (10). Patients were interviewed usually within 2 days and a follow-up questionnaire administered after 6 months.

Injuries were coded according to the 1985 Revision of the Abbreviated Injury Scale (AIS) (11). The Injury Severity Score (12) was modified so that head and neck

injuries were classified separately and external injuries coded under their body region.

Of 1822 bicyclist casualties, 1703 were eligible for study after 119 exclusions: 106 not riding their bicycle at the time of the accident, ten absconding before examination and three who refused interview. The inclusion of seven bicyclists who died at the accident scene provided a total of 1710 eligible bicyclist casualties.

Comparisons were made between unhelmeted casualties and those wearing SAA approved and non-approved helmets.

Statistical analysis

Injury frequencies were compared using the Pearson χ^2 test with Yates' correction or Fisher's Exact test where numbers were small. The structure of this investigation was neither a case-control nor a cohort study. For this reason the usual measures of the odds ratio, relative risk, and logistic regression were not appropriate. The 'relative proportion', the ratio of percentage of injury in helmeted casualties to percentage of injury in unhelmeted casualties, was estimated with 95% confidence intervals. The percentage of risk reduction is 1 – the relative proportion expressed as a percentage. Differences between the ranks of AIS severity scores were assessed by the Mann-Whitney *U* test (two-tailed). SPSS computer software was used for the analysis (13).

Examination and simulated impact testing of helmets

A sample of 64 helmets worn by casualties sustaining a blow to the helmet/head underwent examination and simulated impact testing in relation to the Australian Standard at Technisearch Ltd, Royal Melbourne Institute of Technology (14). Of 61 hard shell helmets with expanded polystyrene foam liners, 55 were SAA approved and three were approved to US Standards. New helmets of the same model as damaged helmets were dropped from different heights in a free-fall assembly until the fall reproduced helmet damage closely resembling that sustained in the accident. The Australian Standard requires that the headform sustain less than 400g radial acceleration in an impact from a 1.5 m drop height (equivalent to an impact into a fixed object at 19.5 km/h).

Post-legislation observations

The following information was provided by Monash Accident Research Centre (MUARC), Vic Roads (Road Safety), Transport Accident Commission Insurance (TAC), and Health Department, Victoria (HD, Vic).

Helmet wearing rates and bicyclist exposure

Overall helmet wearing rates between 1983 and 1992 for Melbourne and country Victoria (Vic Roads/MUARC) (15), and the results of observational surveys of helmet wearing and bicyclist exposure between 1987 and 1992 at Melbourne metropolitan sites (MUARC) for commuting

bicyclists aged 5–11 years, 12–17 years and 18 years of age or over (MUARC) (9).

Bicyclist fatalities

Annual bicyclist fatalities between 1983 and 1993 and the number under 18 years of age (Vic Roads) (16).

Bicyclist casualty hospital inpatient admissions or fatalities after accidents involving motor vehicles

The annual numbers of bicyclists either hospitalised as inpatients in Victoria or killed after collisions involving a motor vehicle for the years 1982/1983–1990/1991 were provided by TAC. The numbers with head and non-head injuries in the first and second years following legislation have been compared with those of the prelegislation year (MUARC) (9).

Bicyclist casualty public hospital inpatient admissions

The number of bicyclist casualties admitted to Victorian public hospitals with head and non-head injuries between 30 June 1989 and 1 July 1991 (HD, Vic/MUARC) (9).

Results

Injury profiles of 1710 bicyclist casualties wearing and not wearing helmets

In all, 366 (21.4%) casualties were wearing a helmet. Of these 261 (15.3%) wore SAA approved and 105 (6.1%) non-approved helmets.

Sex-age distribution

Males outnumbered females four to one in each group: unhelmeted, approved helmet wearers and non-approved helmet wearers. Sex distribution did not differ significantly. There were no significant mean \pm SD age differences between unhelmeted (17.7 ± 11.5 years) and approved helmet wearers (16.3 ± 11.9 years), but non-approved helmet wearers, males and females, were significantly older (28.4 ± 13.9 years).

First object struck by bicyclists

A total of 830 (48.5%) bicyclists struck the ground first, 521 (30.5%) a motor vehicle, 109 (6.4%) a fixed object and 209 (12.2%) and another object (unknown 41 (2.4%)). There were no significant differences between groups except for non-approved helmet wearers who struck other objects more frequently ($P < 0.01$).

First object struck by head, face or helmet

The head, face or helmet was struck in more than half the accidents (Fig. 2). The distribution of first objects struck did not differ significantly between helmeted and

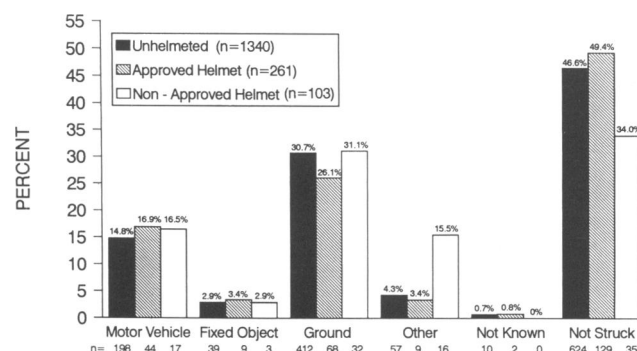


Figure 2. First object struck by head, face or helmet.

unhelmeted casualties. The first and second most common objects struck were the ground and a motor vehicle.

Helmet dislodgements

Fifteen (4.4%) helmets, 9 (3.5%) approved and 6 (5.7%) non-approved, were dislodged in the accident. Two approved helmets and one non-approved helmet were known to have come off after the first impact. Three approved and two non-approved helmets dislodged when the retention system had not been secured by the wearer.

Fatalities and causes of death

Death occurred in two helmeted and 12 unhelmeted casualties. The fatality rate of approved helmet wearers (0.4%) was half that of non-approved helmet wearers (1.0%) and unhelmeted casualties (0.9%) (NS). The two helmeted fatalities died from multiple injuries, including head injury, whereas half the unhelmeted fatalities died from head injury alone.

Head injury, frequency and severity

Head injuries were significantly less frequent in approved helmet wearers (21.1%) and in the total group of helmet wearers (24.6%) than in unhelmeted casualties (34.8%) (Fig. 3). There was no significant reduction for non-approved helmet wearers. The relative proportion of

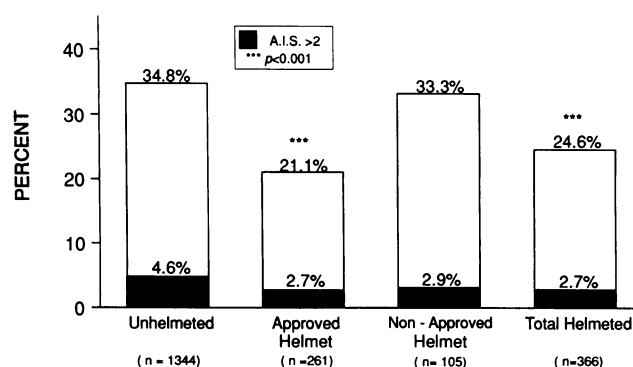


Figure 3. Head injury frequency and severity in unhelmeted and helmeted bicyclist casualties.

helmeted casualties with head injury was 0.71 (95% CI 0.58–0.86) and of approved helmet wearers 0.61 (95% CI 0.47–0.77), representing head injury frequency reductions of 29% and 39%, respectively. Head AIS scores were also significantly decreased ($P < 0.001$). Head injury with AIS scores 4–6 occurred in 0.9% total helmeted wearers compared with 2.0% of non-wearers ($P = 0.10$).

Face injury

Face injury was less frequent in approved helmet wearers (24.9%) than unhelmeted casualties (34.5%) ($P < 0.01$). The relative proportion was 0.72 (95% CI 0.58–0.90). AIS scores were lower ($P < 0.01$).

Neck injury

The frequency of neck injury was significantly increased only in the total helmeted group (5.7% vs 3.3% unhelmeted) ($P < 0.05$). Two injuries attained AIS 3.

Chest, abdomen/pelvic girdle injuries

There were no significant differences.

Extremity/pelvic girdle injuries

Extremity/pelvic girdle injuries were more frequent in approved (89.7%) and non-approved (88.6%) helmet wearers than unhelmeted casualties (76.6%) ($P < 0.001$); ($P < 0.01$), respectively, and AIS scores increased ($P < 0.001$).

Non-head injury severity scores

Non-head ISSs (mean \pm SD) for approved and non-approved helmet wearers were 4.07 ± 4.28 and 4.30 ± 3.76 , respectively, compared with 3.29 ± 4.51 for unhelmeted casualties ($P < 0.01$ and $P < 0.05$, one-way analysis of variance).

Distribution of head and other injuries

No helmeted casualty sustained a head injury alone compared with 63 (4.7%) unhelmeted casualties (Fig. 4). Head with other injury was also significantly less frequent in approved helmet wearers (21.1%) than the unhelmeted (30.1%) ($P < 0.05$). Non-head injury alone was correspondingly more frequent (78.9%) in approved helmet wearers than unhelmeted casualties (65.2%) ($P < 0.05$).

Head injury frequency and severity after controlling for non-head ISS

When controlled for non-head ISS < 15 , head injury was less frequent (20.3%) in approved helmet wearers than unhelmeted casualties (31.1%) ($P < 0.001$) and head AIS scores lower ($P < 0.001$). For non-head ISS > 9 and > 15 the reductions did not attain significance.

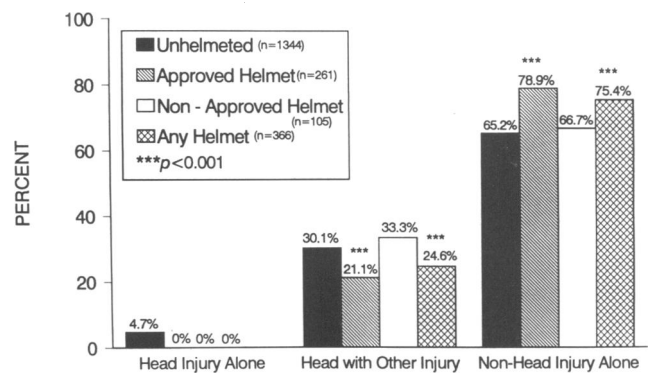


Figure 4. Frequency of head injury alone, head injury with other injury and non-head injury alone in unhelmeted and helmeted bicyclist casualties.

Head injury frequency and severity after exclusion of casualties with dislodged helmets

After excluding 15 helmet wearers whose helmets dislodged and seven in whom dislodgement was uncertain, head injuries were less frequent in helmeted (21.5%) than in unhelmeted riders (34.8%). The relative proportion was 0.62 (95% CI 0.50–0.77) with a head injury risk reduction of 38%. For approved helmet wearers the relative proportion was 0.55 (95% CI 0.42–0.71) ie an estimated head injury reduction of 45% (Fig. 4). AIS scores were also significantly reduced ($P < 0.001$).

Bicyclist helmet performance in accidents: simulated impact testing

Of the 64 helmets sampled, 33 (52%) were from accidents involving a collision with a motor vehicle (14). A bitumen road was struck in 52 (62%) helmet impacts and in 21 (25%) a motor vehicle. Four helmets had no evidence of an impact and two badly damaged helmets were non-evaluable. The remaining 58 helmets sustained 84 impacts, of which 54 (64%) occurred below the SAA test line. Of the 84 impacts, 68 could be assessed for radial acceleration after eight exclusions: one helmet run over, three helmets with more than one impact at the same site and four helmets which dislodged. In all, 61 (90%) impacts were reproduced from a drop height of less than the 1.5 m of the Australian standard. Six required drop heights between 1.5 and 2.25 m and one 2.4 m. No impact attained the 400g allowed by the Australian Standard. Only 7 (10%) impacts exceeded 200g, with one attaining 335g. When a helmet was not dislodged or run over no head injury exceeded AIS 3.

Post-legislation observations

Helmet wearing rates and bicyclist exposure

The overall wearing rate for Melbourne metropolitan commuting and recreational bicyclists of all ages increased from 32% in 1990 prelegislation to 65% in the first post-legislation year and to 76% in the second. The increase in country Victoria was from 18% in the prelegislation year

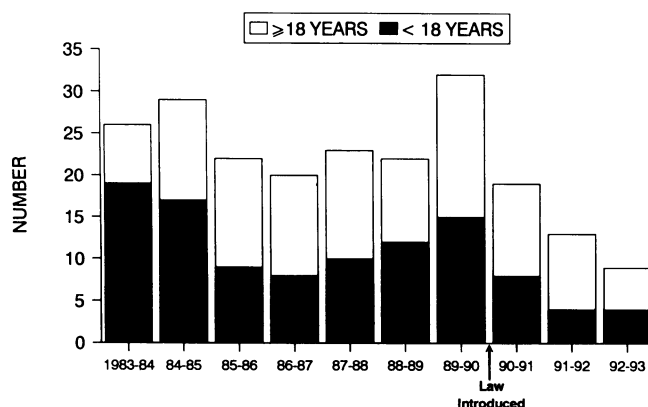


Figure 5. Victorian bicyclist fatalities for financial years 1983–1984 to 1992–1993. Mandatory wearing legislation was introduced on 1 July 1990. The numbers aged 18 years or over and under 18 years are given.

to 78% in the first post-legislation year. The Victoria-wide rate increased comparably from 31% to 75% (15).

Figure 1 shows that helmet wearing rates of child, adolescent and adult commuting bicyclists in metropolitan Melbourne sites more than doubled after legislation (9).

Although adolescent cycling decreased 40% after legislation, adult exposure and total exposure continued to increase.

Bicyclist fatalities

Fatality numbers decreased from 77 in the 3 years before legislation to 41 in the 3 years after legislation (Fig. 5). Of the fatalities, 85% were male. Fatalities in under 18-year-olds decreased comparably from 37 to 16.

Bicyclist casualty hospital inpatient admissions or fatalities after accidents involving motor vehicles

Figure 6 shows a 48% reduction in the number of serious bicyclist casualties with head injury in the first year after the law and 70% in the second compared with the year

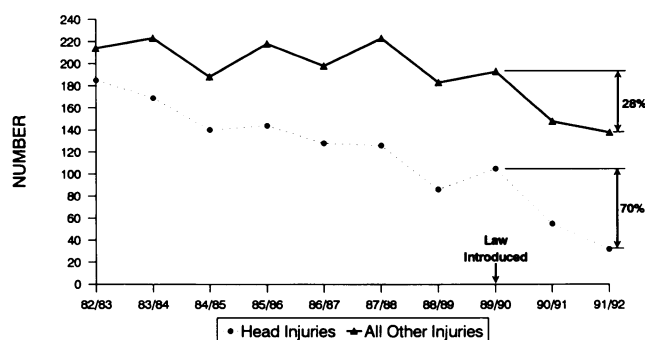


Figure 6. Number of bicyclist casualties with head or other injuries between July 1982 and June 1992 admitted to Victorian hospitals as inpatients or killed after collisions with motor vehicles.

preceding legislation (9). The number with serious non-head injury in the second year fell by 28% compared with the prelegislation year.

Bicyclist casualty public hospital inpatient admissions

The number of bicyclist casualties admitted to Victorian public hospitals with head or non-head injuries decreased 37% and 21%, respectively, in the first year after legislation compared with the year before legislation (9). Data are not yet available for the second post-legislation year.

Discussion

The promotion of voluntary helmet wearing by bicyclists in Victoria was initiated by recognition of their high vulnerability to head injury in comparison with helmeted motorcyclists and the availability of the first helmet approved to the Australian Standard. Mass media education and school publicity led to progressive increases in the helmet wearing rates of all age groups, albeit with lower adolescent participation. Reduction in helmet purchase costs through the Government rebate scheme and a wider range of more aesthetically pleasing helmets assisted the achievement of high voluntary wearing rates. By the late 1980s these attained levels making the mandatory wearing legislation of the 1 July 1990 feasible. All other Australian states and territories have subsequently enacted similar legislation.

The benefits of helmet wearing in reducing head injuries has been supported by the findings of a comparative study of 1710 bicyclist casualties wearing and not wearing helmets and by post-legislation reductions in bicyclist fatalities and serious head injuries. Both the frequency and severity of head injuries were reduced significantly in bicyclist casualties wearing approved helmets. The estimated reduction in head injury frequency for helmeted bicyclists was 29% and for approved helmet wearers 39%. When helmet dislodgements were excluded the reduction in head injury attained 45%. The actual reductions in head injury risk will exceed these estimates because some bicyclists receiving a blow to the helmet will not sustain head injury and hence will not present to hospital emergency departments. The head injury risk reductions estimated are comparable with those reported for helmeted motorcyclists (10).

The reduction in facial injuries and increase in neck injuries in helmeted casualties can be attributed to the effects of helmet wearing. The greater proportion of non-head injuries in helmeted casualties is explained at least in part as a corollary of the reductions in head injury alone and head with non-head injury consequent to helmet wearing.

Head injuries were not significantly lessened in non-approved helmet wearers. The inclusion of poor quality helmets and the smaller sample size may explain this finding.

The characteristics of the bicyclist casualties investi-

Table I. Comparison of head and non-head injuries in Melbourne and Seattle bicyclist casualties wearing and not wearing helmets

	Head injury	No head injury	Total	% Head injury
Helmet	89	276	365	24.4%
No helmet	463	875	1338	34.6%
Total	552	1151	1703	
Melbourne: seven dying before reaching emergency department excluded				
Helmet	10	110	120	8.3%
No helmet	116	432	548	21.2%
Total	126	532	668	
Seattle: 109 forehead lacerations reassigned				
	Relative proportion		% Risk reduction	
Melbourne	0.70 (95% CI = 0.58–0.86)		30%	
Seattle	0.39 (95% CI = 0.21–0.73)		61%	

gated in the present study were similar to other reports in the predominance of males, age distribution and the first object struck (10). The high frequency of head injuries as the cause of death was in accord with previous findings (10). Whereas the two deaths in helmeted casualties resulted from multiple injuries, six of the unhelmeted fatalities died from head injury alone.

Simulated impact testing and examination of 64 sampled helmets showed that almost two-thirds of the impacts occurred below the test line of the Australian standard. Notwithstanding this, none exceeded the maximum 400g radial acceleration permitted by the standard. When the helmet was not dislodged or run over no head injury exceeded AIS 3. Because more than half of these helmets were obtained from bicyclists involved in motor vehicle collisions, the findings suggest, contrary to the view implied in the Foreword of the British Standard (17), that helmets provide protection in most impacts sustained in such collisions.

The results of this investigation have led to recommendations for improvements in the Australian Standard. A lowering of the current test line, increase in the SAA test drop height and the introduction of a dynamic helmet stability test are under consideration in its current revision.

Although data remain limited on the effects of legislation, considerable reductions have occurred in bicyclist fatalities and inpatient admissions of bicyclists with head injury, including those after collisions with motor vehicles. Overall, helmet wearing rates, which more than doubled in the first year after legislation, continued to increase for all age groups in the next year. The level of law enforcement has been low. Adolescent wearing rates, although remaining the lowest of all age groups, showed a similar trend and attained 59% in the second post-legislation year. Overall, bicyclist exposure increased despite a marked reduction in adolescents' cycling which is considered to reflect their hostility towards the legislation. The post-legislation years coincided with an economic recession, decreased motor vehicle usage and a marked decline in the Victorian road toll. Fewer bicyclists

were admitted to hospital for non-head injuries. Despite these confounding factors the reductions in fatalities, number and proportion of public hospital inpatient admissions with head injury, including those after collisions with motor vehicles, give substantial support to the benefits of helmet wearing by bicyclists and to the promotion and enactment of mandatory legislation.

The study of 1710 bicyclist casualties wearing and not wearing helmets closely resembles a case-control study reported from Seattle, Washington (18). For direct comparison it has been necessary to reassign Seattle casualties with forehead lacerations from case to emergency room controls and exclude the seven fatalities at the accident scene from the Melbourne data (Table I). The Seattle casualties included those with hairnet helmets, hence comparison has been made between all helmeted casualties. The estimated risk reductions for Seattle and Melbourne were 61% and 30%, respectively (39% for SAA approved helmets). The possibility that helmeted bicyclists are more cautious riders could not be excluded in the Seattle study. Another study undertaken in Seattle at that time reported that helmeted bicyclists were more frequently black than white, more frequently rode in parks and were more often accompanied by adults (19). In the Melbourne study helmeted casualties had higher non-head injury severity scores than unhelmeted casualties and were also slightly more frequently involved in accidents in which the head/face or helmet was struck by a motor vehicle. These findings do not support a more cautious riding behaviour by Melbourne helmeted bicyclists. The reduction in head injuries is considered to be a consequence of the protection provided by helmet wearing.

Recently, a study on head injury in 445 child bicyclist casualties wearing and not wearing helmets has been reported from Brisbane (20). Applying relative proportion estimates to their data shows a 39% head injury reduction in helmeted casualties. Their data included 16 casualties with unknown helmet wearing status and with worst assumptions the reduction was 29%. These findings closely resemble those of the Melbourne study.

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Figures 2, 3 and 4 are slightly modified from those published in an article by the author, J C Lane, G A Brazenor and E A Debney in the *Journal of Trauma* (10) with permission of its Editor.

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